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This publication includes two papers heard by the Sub-Committee of the Structures and Materials Panel charged with investigating design cases for future combat aircraft. The papers survey the present situation, in which combat aircraft are flown through manoeuvres not envisaged when the design cases were drawn up, and consider what may happen in the near future, and in particular, the influence that active control may exert. Some suggestions are made about the way in which design cases might be formulated; the topic is one which is to be discussed at a future Panel Specialists' Meeting.

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Combat Loads on Modern Fighters.

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CONTENTS

SELECTING DESIGN CASES FOR FUTURE AIRCRAFT

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SUMMARY

A number of factors which influence the selection of design cases are examined in the light of modern fighter usage and modern technologies that are available, or will soon be available. It was found that pilots fly fighters very differently than was the norm for the period of time when most design criteria specifications were written, largely because the environment created by today's detection systems and weapons is very different than it was then. It was found that technology advances, such as advanced composite construction and fly-by-wire control systems make it possible to tailor the configuration to achieve maneuvering capability previously unattainable. It is concluded that methods of selecting design cases need to be updated. Available methods for predicting loads for new, more complex design cases are discussed. No firm recommendations can be made, but a number of suggestions are made which, it is hoped, will contribute to fruitful future consideration of the problems discussed.

INTRODUCTION

In recent years it has become apparent that modern fighters are not flown in the same way that the older fighters were. A number of factors contribute to this situation. At the time the design specifications were written, the fighter pilot's goals were to either line up his guns on an opposing fighter, or take evasive action to avoid opposing gunfire. In addition, the energy maneuverability of fighters was rather low, as was the maximum speed. Detection of opposing aircraft was visual, which meant that the engagements tended to occur at fairly low speeds, because such limited range made high speed engagements too short to be effective.

Today's combat pilot is faced with the problem of minimizing detection, and being located by very accurate ground based radar, airborne radar and the homing devices carried by a variety of ground-to-air and air-to-air missiles. The availability of AWACS airplanes extends the advantages of accurate radar detection comparable to land based radar to an attacking force. The pilot finds himself in an environment where it is essential to take evasive action for long periods to prevent long range radar from locking on to his position, and where engagements with other aircraft (or missiles) are initiated outside of visual range at very high speeds. In addition, as the speed during the engagement deteriorates, the risk of a lock-on by another opposing fighter increases. The decision as to when to break off an engagement becomes critical, and, in fact, without sufficient acceleration and speed, breaking off may not be possible.

Given the current situation, and given the efforts of designers to present the pilot with maximum advantage, pilots have developed a set of maneuvers that are very different from those described in the design specifications, and the purpose of this paper is to take a first step toward determining whether current specifications are sufficient for structural design, and if not, what changes might be recommended. Certain specific technology developments of recent years are examined in the light of their possible effect on fighter tactics. Some are relatively easy to evaluate, and, as might be expected, others are not.

Most of the discussion of tactical maneuvers is based upon interviews with two experimental test pilots at Grumman Aerospace. Between them these pilots have a great deal of experience in a wide variety of fighter airplanes up through modern operational airplanes like the F-14A plus time in simulators for configurations that have not flown yet, and which may never be flown. This is not to say that all pilots fly the same way, or use exactly the same tactics in the same situation. All of the maneuvers discussed here are not likely to be used by one individual pilot, but we hope represent something approaching the outer edge of the scatter band without reaching it.

In addition to the change in pilot tactics, a number of new technologies have been developed, some of which are being incorporated in new designs, others which are being investigated by the use of technology demonstrators, and still others that are being investigated by simulations of various kinds.

NEW TECHNOLOGIES

Composite Construction

As a technology in itself, composite construction should not alter design requirements, except insofar as it allows a higher thrust-to-weight ratio. It is inherently fatigue resistant, except for metallic substrates, and connections. It does not corrode. However, composite matrices currently used are sensitive to ultra-violet radiation, and need to be protected from sunlight. In addition, the matrices are not suitable for high temperature use, and any design must consider heating from all sources including aerodynamic heating at very high speeds. The characteristic that makes composite construction fatigue resistant is also the source of some concern - it has no yield point, so that overstressing cannot be detected by a visual inspection. Another problem that has emerged is that composite skins are thick, and when used for very thin wings, the room left for fuel is very small.

Aeroelastic Tailoring

This concept has largely developed as a consequence of the characteristics of composite construction. The ability to alter the elastic characteristics by varying the orientation of the fibers offers the opportunity to regulate the deformation of wing structures in a way that improves the aeroelastic characteristics. The most dramatic use of this characteristic appears to be in delaying divergence of swept forward wings so that they become practical for high speed airplanes. The X-29A now being flown at Dryden Research Center has been constructed to demonstrate the practicality of tailoring for forward swept wings. Studies conducted to evaluate tailoring for swept back wings seem to indicate that any improvement would be relatively small, and would not be a driver in selecting composite construction for a design.

High Flexibility

The search for improved performance, particularly high energy maneuverability, has led to the use of thinner and thinner airfoil sections. Thinner sections naturallly result in more flexible wings, particularly in bending. For swept back wings this has resulted in loss of efficiency due to aeroelastic twist in the streamwise direction due to the high bending deflections. And for swept forward wings it has resulted in metal wings being impractical for high speed flight.

Active Controls for Static Stability

The most noticeable effect of active controls used for stability modification (usually, but not always, augmentation) is that it is not possible to perform the mandated maneuvers of the specifications. Dynamic pitching and rolling maneuvers cannot be performed exactly as required by the specifications, with pitch being the most different. However, because the systems are designed to make the handling qualities more nearly resemble those that pilots are familiar with (i.e. older airplanes), the effect on the loads is minimal, and in fact, such systems are sometimes used for limiting the loads.

High Maneuver Rates at High Dynamic Pressure

This has already become one of the more serious problems in calculating loads. The formulae given in the design specifications for establishing maximum normal force coefficient for high pitch rates are not correct. In addition, for airplanes which develop a significant amount of lift on the fuselage, the wing loads may be greatly underestimated. Airplanes which have wide bodies, and utilize vortex lift do not have an easily defined stall point, because they remain controllable to angles of attack up to 90 degrees without excessive buffet.

Smart Weapons

These are of particular interest in the calculation of landing loads for carrier based airplanes. While they aren't too much of a problem for a new design, they can create a serious problem for older designs being retrofitted with such weapons, whether land or carrier based. They can also be a problem in rolling maneuvers, since it is not desirable to jettison such weapons even if attacked by opposing aircraft.

Operation at Large Rates/Incidences

For some time, there has been speculation that control surface rates and airplane rates introduce unsteady aerodynamic terms into the airplane loads. In addition, there has been speculation that the vibration modes become important to the inertia loads. Certainly this is true in the calculation of gust loads. There is a report relating to the F-15 that leads to the conclusion that unsteady aerodynamic terms may be of importance to the horizontal tail motion in a dynamic pitch maneuver. The work was not extended to loads, however. A six-degree-of freedom simulation of the X-29A airplane including vibration modes and unsteady aerodynamic terms showed very small differences in control surface motions, with no perceptible effect on loads. The X-29A is a relaxed stability configuration using a canard for pitch control, so the conclusion that the effects on loads cannot be detected may not apply to a more conventional configuration. However, it should be noted that typical control surface rates for fighter airplanes are usually too low to excite the relatively high frequency vibration modes of a normal fighter configuration. A notable exception is the EF-111A airplane. During structural flight testing, it was found that the vertical tail responded to abrupt roll control inputs, because of the large mass of the radome at the tip of the fin.

MANEUVERING CRITERIA

Actual Maneuvers

As mentioned above, most of the maneuvering to be discussed is based on interviews with two fighter pilots, both currently experimental test pilots. One has a great deal of operational experience in F-14A airplanes, the other is the project test pilot. Both have experience in simulations of more recent configurations. The former has flown the X-29A simulator, while the latter has service experience in older airplanes extending back to the F-11. In general, the two pilots agreed with each other and with comments made by other pilots in informal conversations with the author over a number of years, but it should be emphasized that not all fighter pilots, or squadrons operate in exactly the same way, and differences in tactics from pilot-to-pilot and from squadron-to-squadron are quite common.

Engagements are initiated at high speed (M=1.1 to 1.2 and 350 knots indicated). Detection takes place as the opposing aircraft are approaching each other which necessitates a turn to engage the opponent. This in turn resembles the rolling pullout required in the older design specifications. The airplane is rolled starting at level flight and the load factor is added to complete the turn. Current

specifications do not include this type of maneuver.

Pilots are taught not to let speed bleed down too far because of the possibility of being attacked by another airplane in the area, or ground-to-air missiles, with insufficient speed to take evasive action. However, the speed does often bleed down to low values, particularly in ACM practice. In this situation, the maneuvering develops into a scissoring action of the two airplanes. These rolls tend to resemble the specified rolling maneuvers with a significant difference. The specification maneuver is described as a roll from a bank in one direction at load factor to an equal bank and load factor in the other, with no fore and aft motion of the stick. In fact, pilots usually push the stick forward while rolling, and pull it back again during the check. This is because airplanes roll faster at low angles of attack, and the pilots usually attempt to maximize their roll rate to shorten the maneuver time.

Barrel rolls are quite common during air combat maneuvering. The maneuvers consist of a partial stick roll at high load factor to line up on the target for firing.

Jinking maneuvers consisting of a series of rolls and positive and negative load factor maneuvers are frequently used to evade another airplane, or to confuse enemy radar in a heavily defended area. When used to evade another airplane, they usually involve rather high negative load factor. However, statistical data show very few high negative load factor maneuvers (greater than -2.0g), which probably reflects the instruction to break off the engagement when the speed bleeds down.

When the airplane speed does bleed down, pilots prove to be quite inventive in developing maneuvers that will give them a tactical advantage. Although some airplanes are equipped with automatic maneuver flaps and slats, pilots tend to use the landing flap position for added maneuverability, even though this is not a specified design case. It is hard to believe that, under these circumstances, the design flap speed and load factor are not exceeded fairly frequently. For airplanes with adverse yaw characteristics at low speed/high angle of attack conditions, pilots are known to induce a sort of controlled departure by crossing the cockpit lateral and directional controls to make the nose swing in the proverse direction. Pilots are known to pull circuit breakers when they feel the need for more control than the flight control system allows. It should be clear that these departures from normal operation are usually developed in the ACM practice environment, and involve a building up to the final maneuver as used for (more or less) normal operation.

From a very limited amount of simulator work, it appears that tactics for airplanes with very efficient wings and high thrust to weight ratio will not be very different from less capable airplanes. The advantage derives from the higher energy available to prevent speed from bleeding down as quickly. This advantage, of course, will force an opponent to break off the engagement. The ability to choose to engage, or break off is an important advantage to a fighter pilot.

The use of side force generators and devices providing direct lift control introduce a whole new dimension into fighter tactics. It is extremely difficult to predict how pilots will use such devices, because it seems that every time a new capability is introduced to pilots, they devise schemes for its use that were not thought of by the designer. The use of landing flaps for maneuvering mentioned above is a primitive form of direct lift control that is in current use, and the use of crossed controls provides a capability similar to side force generators. It would seem that these devices will probably reduce the dependence on rolling maneuvers to position the aircraft.

DESIGN CRITERIA

Design Speeds

Current specifications require maneuvering at high speeds, but consideration should be given to extending the maximum load factor capability into the low supersonic range, rather than allowing a reduction at M=1.0.

Rolling Maneuvers

The type of rolling maneuver used to initiate an engagement is no longer required by design specifications, although the flight test specifications still include the demonstration of a roll initiation in level flight, and then a pull to load factor. The substitution of the currently specified maneuver in which the roll is initiated at load factor with the stick fixed in the fore and aft position during the roll apparently results from the belief that airplanes tend to pitch up during a roll, and that they roll just as fast at high load factor as they do in level flight. Neither of these beliefs is necessarily true. Some airplanes pitch down, and most airplanes roll faster at low angles of attack. The scissoring type of maneuvering also requires a different simulation than the current specifications require. A reduction in load factor to increase the roll rate is very common, and can be seen in records of actual flying when the pilot is not instructed to perform the maneuver exactly as required by the design specification. There has been a report that a current fighter encountered very high vertical tail loads in performing a series of rolling maneuvers, because the sideslip angle built up with successive maneuvers. This has not been confirmed, and could not be duplicated in a computer model of another configuration.

Jinking Maneuvers

Jinking maneuvers are a series of symmetrical and unsymmetrical maneuvers. There is little question that current specifications do not adequately address these maneuvers. However, there is no evidence that flight failures have occurred due to inadequate design. All that can be said is that ultimate load was not exceeded, and that permanent deformations are not common.

These load cases are of immediate concern, along with the unauthorized use of landing flaps and other devices not intended to be used for air combat maneuvering. The issue of new devices (side force generators, direct lift control, etc.) has to be considered separately, because there is no experience with them.

CALCULATION OF LOADS

Maneuver Simulation

The ability to simulate complex maneuvers is available to the loads engineer now. It is necessary to have available six-degree-of-freedom simulation including the ability to enter non-linear aerodynamic data as well as structural flexibility, including vibration modes and unsteady aerodynamic terms. It is necessary to be able to accurately model the control system, because all designs include stability modification systems, and relaxed stability configurations will soon be common. Forward swept wing technology requires that gust simulations be an important part of the analysis. But gust is another problem, not part of this discussion. An opportunity to test current simulation techniques in relation to all these considerations has been proven by the X-29A technology demonstrator, and full advantage is being taken of it.

Load Distribution

The problem of calculating load distributions is becoming more difficult. With the complex maneuvers being introduced, and demands for more accurate (less conservative) loads to take maximum advantage of new materials and to minimize weight, the load distribution calculation picture has forced the loads engineer to re-examine his assumptions. It cannot be assumed that linearizing aerodynamic data is conservative, particularly for forward swept wings. This opens up the problem of calculating pressure distributions when the flow is partly separated. If the assumption is made that wind tunnel results can be obtained in a timely fashion, the problem of aeroelastic corrections in the non-linear range is still there to be considered. Work has been done in the field of aeroelastic effects in the non-linear aerodynamic range, and has been applied in the calculation of X-29A load distributions as well as coefficient corrections for six-degree-of-freedom simulation. However, there does not appear to be any way of handling non-linear structural deformations in conjunction with non-linear aerodynamics at the present time.

Determining load distributions is particularly difficult in the transonic range, because transonic codes for loads work, including aeroelastics, are not available, certainly not in the partly separated range. The use of wind tunnel data is not entirely satisfactory, because dynamic parameters cannot be simulated very accurately. In addition, there is the question of defining a minimum Reynold's number, which has been the source of a great deal of discussion for many years. A great deal of work has been done in these fields, but little specifically directed to the determination of loads, which tends to demand a level of accuracy not needed in most other aerodynamic work.

DESIGN STRESSES

In general, the determination of internal loads seems to be in somewhat better shape than the calculation of the load distributions. Of course, this may be the inevitable prejudice of the one who does not have to calculate internal loads, but does have to calculate external loads. It seems, though, that if we are able to determine what the external loads should be, the people who develop finite element models can do a satisfactory job of predicting internal loads, especially in view of their ability to obtain element tests, and eventually a static test of the complete structure. However, the question of structural behavior in the non-linear range is still present as an unsolved problem for the sometimes very flexible structures we will be working with in the future. The loss of a new design trainer during flight testing several years ago may have been due to non-linear behavior of the structure resulting in unpredicted divergence.

CONCLUSIONS

To attempt to draw any definitive conclusions from the discussion above, seems like an exercise in futility. Perhaps this section should be called SUGGESTIONS. However, certain comments can be made.

The classic way of defining design cases in a general specification cannot be supported any longer. The USAF has recognized this problem, and its proposed new specification attempts to address itself to the solution of the problem, but it seems to this author that it has overshot the mark, and is too vague in many respects.

Although it seems that the capability to model the necessary maneuvers in a computer program to select design cases exists, the problem of determining the loading distributions remains a serious problem. Wind tunnel testing cannot provide the data needed for the highly dynamic cases that will result from more realistic maneuver modeling, and existing theoretical methods cannot adequately model the partially separated flow that occurs quite regularly in real maneuvering. It has been suggested that perhaps relatively inexpensive subscale airplanes similar to those used recently for low speed handling qualities investigations might be a solution. This necessitates design into the transonic range at the least. A conversation with the designer of these sub-scale airplanes led to the conclusion that there was no reason why such an airplane couldn't be designed, built and flown, but a feasibility study is certainly in order to determine whether it would be cost effective.

It appears that simulator work involving real pilots flying ACM missions should be supported for as many configurations as can be conceived of as being useful in the near future. Such facilities exist, and are equipped to record airplane kinematic parameters for two opposing airplanes which can be used to evaluate the loads implications of the maneuvers used by the pilots in a realistic atmosphere.

REVIEW OF DESIGN LOAD SITUATION

by
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SUMMARY

The philosophy of the relevant design requirements and the essential load parameters for the manoeuvre load conditions, including the determination of the control displacements from MIL-A-8861 to MIL-A-008861 A is reviewed. These MIL-specifications have been applied firstly to an airplane with mechanical flight controls and secondly with a fly-by-wire system that has control laws integrated. After discussion of various influences due to damping modes on control input and on feedback of response parameters, some results for an aircraft with a Control and Stability Augmentation System are shown. Finally, an active controlled aircraft configuration is evaluated. To present an approach to a design load analysis, the time histories of control displacements have been varied.

1. INTRODUCTION

The determination of the design manoeuvre loads is largely specified independently of the manoeuvres actually performed in operation or during missions. The assumption is that the manoeuvres defined in the regulations cover all manoeuvres occuring in operation. The regulations give the time history of the control surface deflections and numerically define several essential load parameters for determination of the load level.

The introduction of the fly-by-wire and/or active control technology makes this philosophy inadequate, though. The latest MIL-Specification A-008861 A does no longer specify the control surface deflections but the cockpit control displacements, whereas the other load criteria are retained. This MIL-Specification has been applied to two airplane configurations and different flight control systems with the aim to show the various influences on structural loads.

2. DESIGN REQUIREMENTS

Aircraft structures are designed in accordance with the relevant regulations and based on a philosophy defining the load level so as to cover all loads expected in service. The design loads are largely determined independently of the manoeuvres actually performed in operation.

The design load conditions are determined by the main load parameters as limit values for:

- symmetrical manoeuvres as load factor (n_z)
- unsymmetrical manoeuvres as roll rate (p), bank angle (ϕ) combined with a specified load factor (n_z)

as shown in Table 1 and 2

TABLE 1 SYMMETRICAL FLIGHT PARAMETERS FOR FIGHTER (MIL-A-008861 A)

BASIC MISSION SYMBOL	SYMMETRICAL FLIGHT LIMIT LOAD FACTOR					Time for abrupt cockpit longitudinal control displacement t_1, second
	Basic Flight Design Weight		All Weights	Max. Design Weight		
	Max	Min at V_H	Min at V_L	Max	Min at V_H	
A, F, TF (Subsonic)	8.0*	-3.0	-1.0	4.0	-2.0	0.2
A, F, TF (Supersonic)	6.5	-3.0	-1.0	4.0	-2.0	0.2
O, T	6.0	-3.0	-1.0	3.0	-1.0	0.2

* as required by Performance and Design Requirements (PDR)

TABLE 2 UNSYMMETRICAL FLIGHT PARAMETERS FOR FIGHTER (MIL-A-008861 A)

Unsymmetrical Manoeuvre	Initial Load Factor		Roll Rate	Bank Angle	Time for abrupt cockpit displacement
	Max.	Min.	[°/s]	[°]	
ROLLING PULL OUT	$0.8 n_z (max)$	1.0	≤ 270	2x value corresp. to n_z	0.1
ROLL 180	1.0	-1.0	≤ 270	180	0.1
ROLL 360	1.0	1.0	≤ 270	360	0.1
YAWING	1.0	1.0	-	≤ 5	0.2

For the determination of the structural loads response calculations of the aircraft for defined control surface displacements are performed, and thus the manoeuvre loads for the whole flight envelope are calculated.

The control surface displacements are defined as time history for

- pitching manoeuvres
- rolling manoeuvres
- yawing manoeuvres

as shown in Fig. 1

In the former MIL-A-8861 specification, the control surface displacement time history is to be determined so as to produce the most critical load conditions.
For example:

- triangular elevator displacement, the maximum elevator displacement is that required to obtain the specified limit load factor in the shortest time.

- trapezoidal elevator displacement, the elevator movement resulting in a ramp-type displacement to obtain the maximum value of the limit load factor at the time when the elevator displacement is being returned to neutral or to the half-opposite displacement.

Application of these control surface movement permits to determine the most critical loads on horizontal tailplane, fuselage and wing for symmetrical flight conditions. This means, this MIL-A-8861 specification, as far as the control surface deflection time histories are concerned includes distinct load criteria that provide a load level which cannot be exceeded by any other control surface movements.

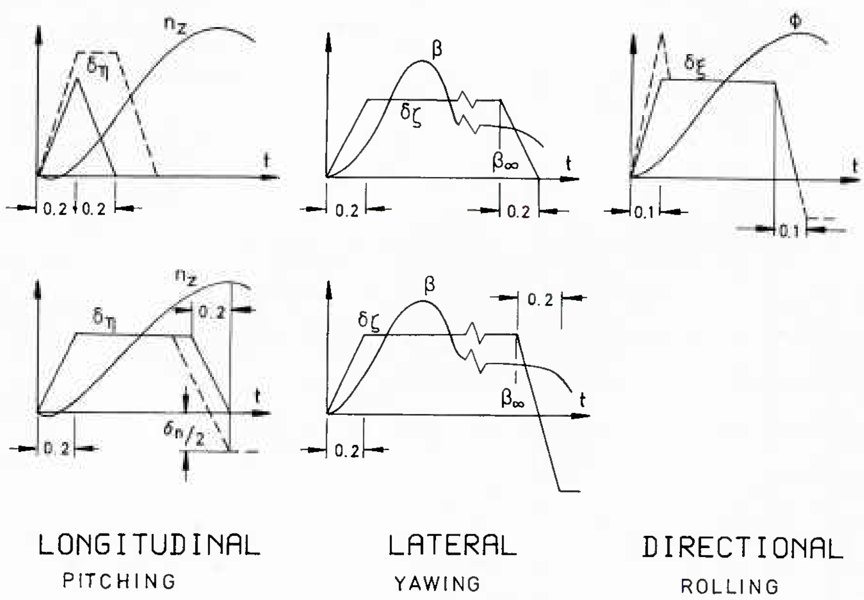


FIG. 1 COCKPIT CONTROL DISPLACEMENT
MIL-A-008861 A

2. APPLICATION OF MIL-A-008861 A TO A/C WITH FLY-BY-WIRE CONTROL SYSTEMS

The latest MIL-A-008861 A specification, instead of the control surface displacement, specifies the cockpit control displacement, retaining the other conditions concerning the load factor to be obtained and the time of checking the manoeuvre. For aircraft the control surface displacement is proportional to the cockpit control displacement, the response of the aircraft and the loads are the same as by application of MIL-A-8861.

Fig. 2 shows, for a triangular elevator displacement, the time history of the load factor and the distinct peaks of horizontal tail loads.
(1) The first peak is the maximum downward load at the maximum elevator displacement.
(2) The second peak is a high upward load at a high load factor and neutral elevator displacement.
Fig. 3 depicts a trapezoidal elevator movement. The manoeuvre is checked so that the elevator displacement is neutral at the time when the load factor has obtained its maximum. The distinct load peaks occur at the points (1), (2), (3).

(1) The first peak is the maximum downward load at a low load factor, which is generally covered by the first peak of the triangular movement.

(2) The second peak gives a high upward load combined with maximum torsion on the tailplane at a high load factor.

(3) The third peak gives the maximum upward load at neutral elevator displacement and the maximum load factor.

Fig. 4 shows, for a rolling pull-out manoeuvre the displacements of the cockpit control and of the control surface due to the actuator influence. The peaks of rolling acceleration as a load indicator occur at the same time when the control surface deflection course is changed. For aircraft with fly-by-wire control systems, in which control laws are integrated, the time history of the cockpit control displacement and that of the control surface have no similarity. In other words, the control surface displacement is different in magnitude and time history. In addition, more control surfaces may be involved. Therefore the aircraft response and also the loads on several structural components are different.

In Fig. 5 the difference between cockpit control and elevator dflection time history for a triangular command is shown, where the control law contains a damping mode for the feedback of the pitch rate. The difference between cockpit control and elevator displacement is also shown for a trapezoidal command in Fig. 6. Fig. 7 shows the influence of pitch rate feedback on the control surface movement for different cockpit control displacements. The most critical case for the horizontal tailplane is the trapezoidal one, which results in a control surface deflection like a fishtail manoeuvre. For all control displacements the level of the load factor is the same.

After discussion of various influences due to damping modes on control input and on feedback of response parameters, some results for an aircraft with a Control and Stability Augmentation System (CSAS) are shown. This aircraft has variable sweep as shown in Fig. 8. Fig. 9 shows the flight envelope for this variable wing sweep aircraft. The v-n diagram for the subsonic, transonic and supersonic regions is shown in Fig.10.

The airplane we are discussing here is an operational sweepable wing aircraft featuring a triplex analogue fly-by-wire control system, mechanical emergency control and automatic stabilization. The primary flight control system provides pitch, roll and yaw control by means of all moving tailplane (taileron), a conventional rudder and mounted spoilers. The tailerons operate in phase for pitch and diferentially for roll control. The spoilers give augmented roll control at unswept and intermediate wing positions at low speeds.

The main sensors for feeding back the aircraft motion are rate gyros. Both, the command signales and the feedback signales are passed through appropriate gain schedulers and filters before they are fed to the control surface actuators. As main scheduling parameters dynamic pressure, wing sweep and a flap switch signal are used. A block diagram of the main elements of the CSAS is shown in Fig. 11.

To this aircraft, MIL-A-008861 A has been applied. First of all, the influence of the actuator and of the Control and Stability Augmentation System are analysed.

The influence on tailplane movement is shown in Fig. 12, presenting:

- the trapezoidal input signal
- the input signal modified by actuator transfer function
- the input signal modified by CSAS and actuator.

These three different kinds of tailplane motions were introduced as manoeuvre input into the response calculation. Fig. 13 depicts the vertical load factor.

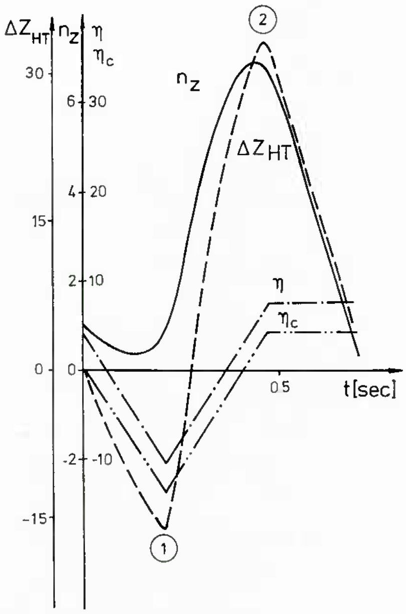


FIG. 2 LOAD FACTOR AND HORIZONTAL TAILPLANE LOADS FOR AN A/C WITH DIRECT SURFACE CONTROL

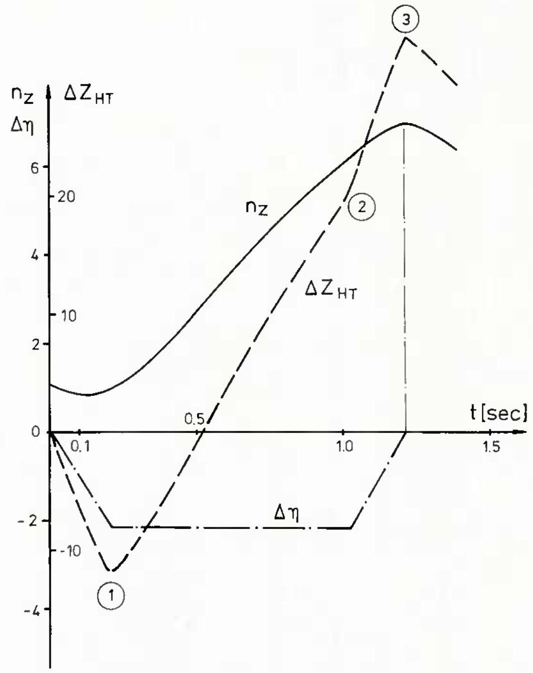


FIG.3 LOAD FACTOR AND HORIZONTAL TAILPLANE LOADS FOR AN A/C WITH DIRECT SURFACE CONTROL

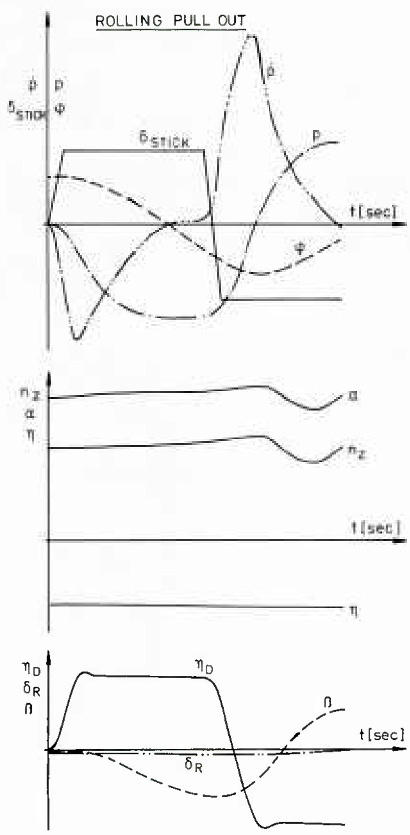


FIG 4 ROLLING PULL OUT PARAMETERS FOR AN A/C WITH DIRECT SURFACE CONTROL

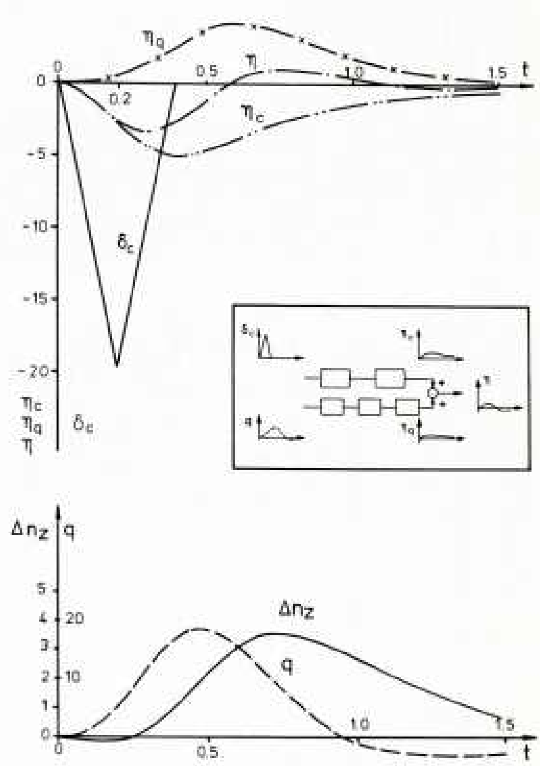


FIG.5 DIFFERENCE BETWEEN COCKPIT CONTROL AND ELEVATOR DEFLECTION TIME HISTORY

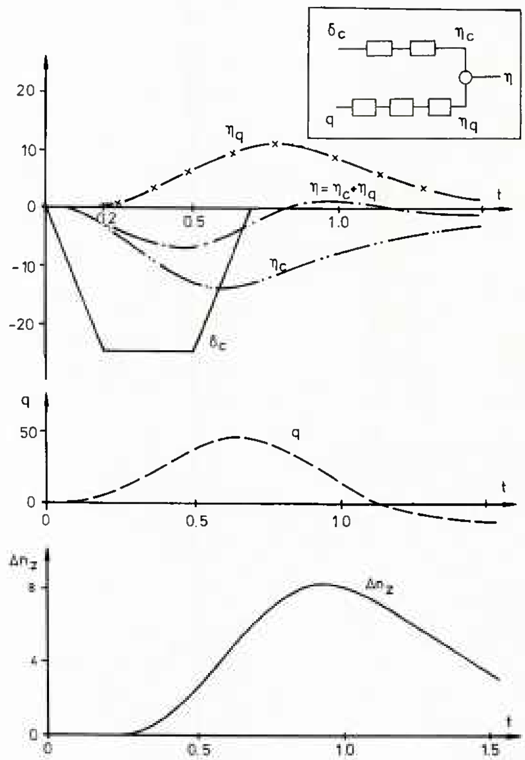


FIG.6 DIFFERENCE BETWEEN COCKPIT CONTROL AND ELEVATOR DEFLECTION TIME HISTORY

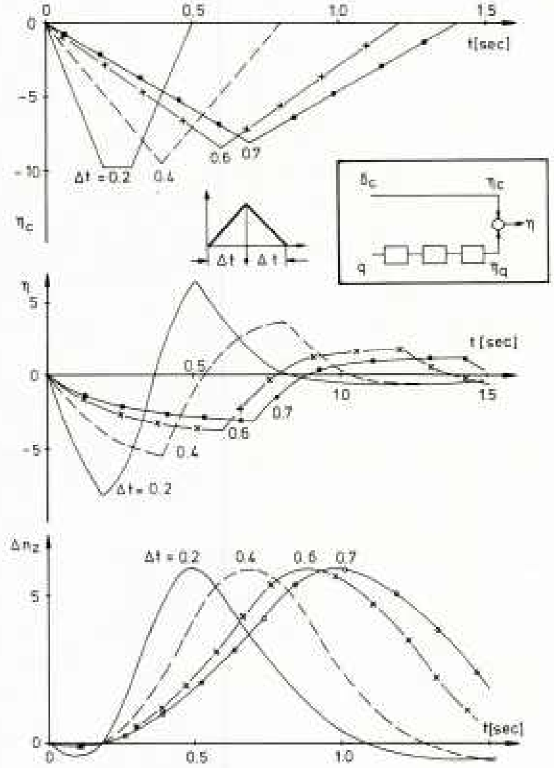


FIG. 7 VARIATION OF TIME (Δt) FOR COCKPIT PITCH CONTROL INPUT

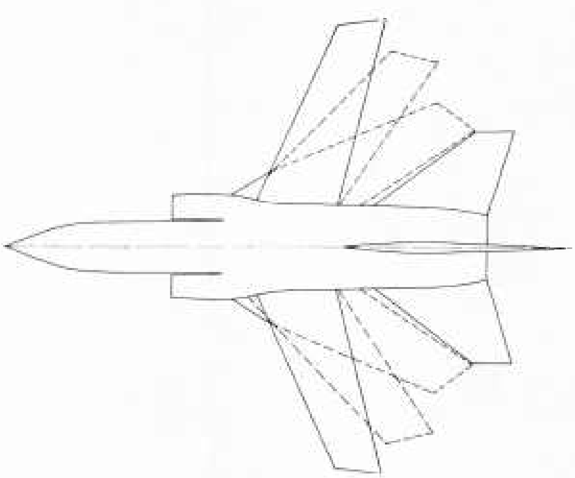


FIG. 8 VARIABLE SWEEP AIRCRAFT

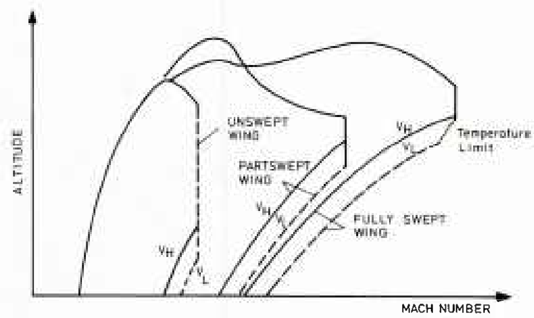


FIG.9 FLIGHT ENVELOPE FOR VARIABLE WING SWEEP A/C

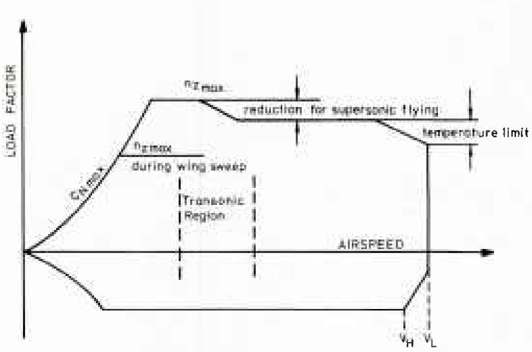


FIG. 10 v-n DIAGRAM FOR SUPERSONIC VARIABLE WING SWEEP A/C

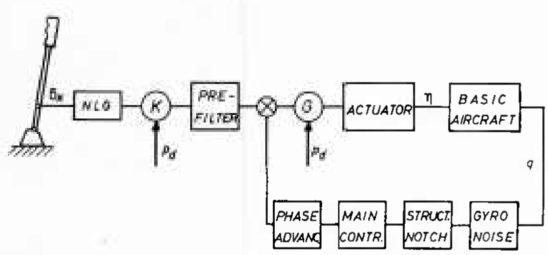


FIG. 11 CONTROL AND STABILITY AUGMENTATION SYSTEM OF SUPERSONIC AIRCRAFT

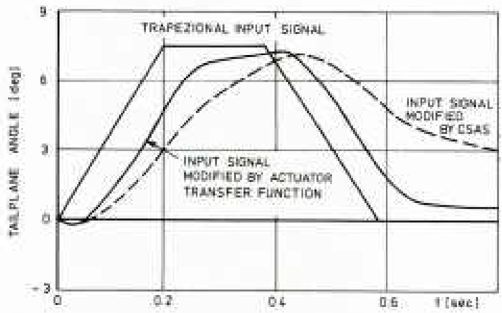


FIG. TAILPLANE ANGLE INPUT SIGNAL

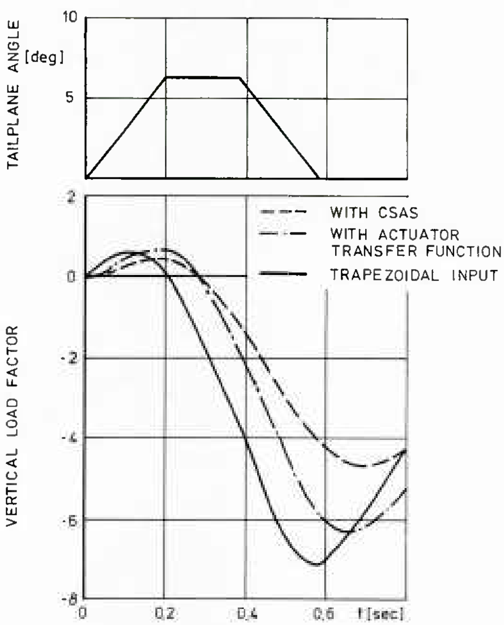


FIG.13 A/C CENTER OF GRAVITY VERTICAL LOAD FACTOR DUE TO MANOEUVRE

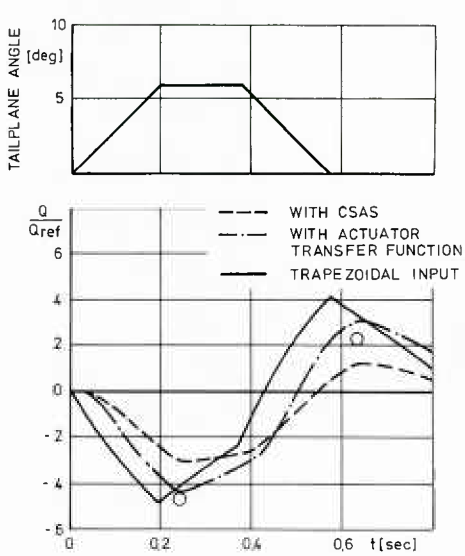


FIG.14 TAILPLANE ROOT SHEAR FORCE DUE TO MANOEUVRE

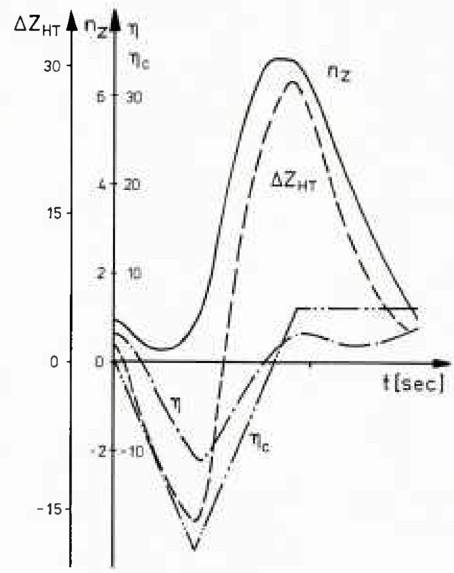


FIG.15 LOAD FACTOR AND HORIZONTAL TAILPLANE LOADS FOR AN A/C WITH CSAS

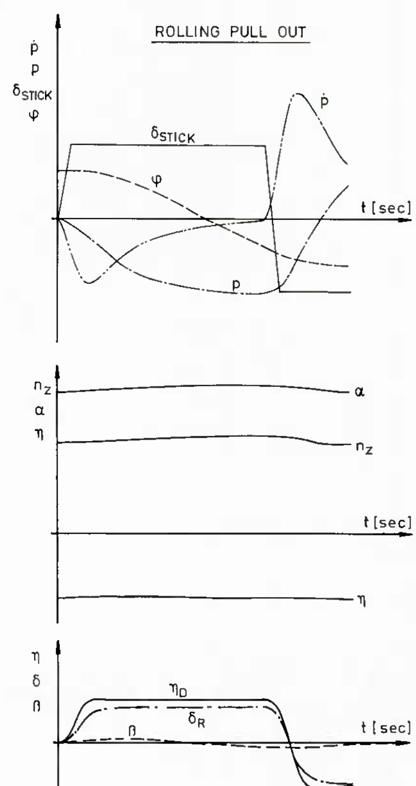


FIG.16 ROLLING PULL OUT PARAMETERS FOR AN A/C WITH CSAS

As expected, the highest values of the load factor results from the trapezoidal input and the lowest from the CSAS input. The difference is more than 2g (65%). But to meet the MIL-Specification, the specified limit load factor is to be obtained and the manoeuvre has to be checked at the time when maximum value of the load factor just has occured. Figure 14 shows the influence of the three tailplane inputs on the horizontal tailplane load. The first load peak for CSAS-input is 63% of trapezoidal input. The second load peak for CSAS-input is 35% of trapezoidal input.

For the determination of design loads the limit load factor has to be obtained. On the assumption that the time history of the input signals has the same checking points but higher tailplane angles as necessary to obtain the limit load factor, the tailplane loads will increase proportionally to the ratio of the corresponding load factor of Fig. 13. With these conditions the tailplane load will be of the same order in the first peak but 54% in the second peak, as compared with the loads due to trapezoidal input, which is indicated by circles in Fig.14.

Now some results for an aircraft with CSAS, applying MIL-A-008861 A are shown. Fig. 15 shows the time histories of the elevator deflection (η_D), the resulatant load factor (n_z) and the tailplane load (Z_{HT}) due to a triangular cockpit control movement. Fig. 16 presents the time histories of the differential tail deflection (η_D), the rudder displacement (δ_R) and some response parameters as bank angle (ϕ), roll rate (p) and roll acceleration ($\dot{p}$) due to a rolling pull-out manoeuvre.

In conclusion it can be stated:
In manoeuvres the control surface displacement is similar to the cockpit control movement, the distinct load criteria are the same as for aircraft with mechanical mode. But if the control surface movement has no similarity to the cockpit control movement, additional variations of control inputs are necessary in order to find the most critical loads acting on the main structural components.

4. EVALUATION OF ACTIVE CONTROLLED AIRCRAFT

Modern combat aircraft taking advantage of design feature as
- carefree handling
- natural instability
- canard configuration

can no longer be designed following the manoeuvres as defined in the MIL-Specification MIL-A-008861 A. The following evaluations are intended to highlight the complexity of design load determination.

For a Delta-Canard Configuration as shown in Fig. 17 some investigations with respect to symmetrical load on the main structural components are presented. The stick command is transmitted to the control surface (foreplane and/or trailing edge flap) by a control system shown in Fig.18. The control system is designed such that maximum forward and maximum aft stick deflection is assigned to minimum or maximum load factors in the whole flight envelope for carefree handling.

First, three different stick input functions are analysed,

- ramp-style stick input
- trapezoidal stick input with return to 1/3-opposite displacement at the time when the maximum value of load factor is obtained
- triangular stick with return to the opposite displacement of 1/3 of maximum deflection.

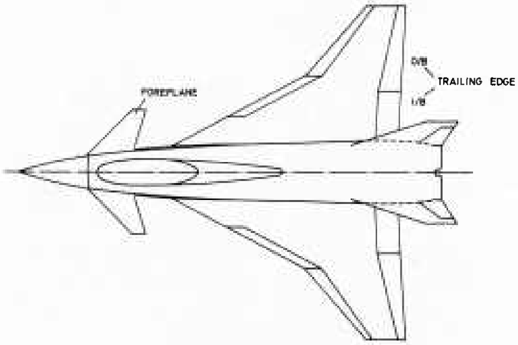
The manoeuvre is performed so that the required limit load factor of $n_z = 9.0$ is obtained but not exceeded. The time history of the load factor and of the activated control surface displacements (foreplane and trailing edge flap) in subsonic manoeuvres is shown in Fig.19. On right-hand side the foreplane loads (NF/P), the flap hinge moments (HM_{TE}), and the pitch acceleration ($\dot{q}$) as representative parameter for the rear fuselage loading are plotted.

Comparison of the triangular stick input with the ramp-style and/or trapezoidal stick input, as required by MIL-Specification permits, the following conclusion:
As exspected, the highest control surface displacements occur during the triangular stick input; the peak value is 1.5 times higher for the foreplane and 1.7 times higher for the flaps than during trazoidal stick input or ramp input, as the case may be. Resulting from the peaks of control surface displacement, with high displacement rates for the triangular stick input, the pitch acceleration is 2.3 times (negative) and 2.8 times (positive) higher. Therefore, the foreplane loads increase at the same ratio whereas the flap hinge moments are in the same order of magnitude.

For manoeuvre in supersonic flight, shown in Fig. 20, the influence of the control input function on the control displacement is 1.2 times higher for the foreplane and for the flap deflection than during trapezoidal input, but the acceleration is 2.0 times higher and therefore the loads on the control surfaces increase by 1.2 times NF/P and 1.1 times for HM_{TE}. Nevertheless the load level is higher than in subsonic flight as presented in Fig. 19.

To determine the effect of the gains for the rate to the foreplane or the trailing edge flaps, the aircraft is controlled with either foreplane or flap and using the non-active control surface for trim purposes only. Fig. 21 and 22 show the results. It can be seen that the highest positive loads on the foreplane occur in supersonic flight when the aircraft is controlled by the foreplane, but the hinge moments of the flaps are insignificantly higher than with the original gain.

FIG. 17 DELTA - CANARD CONFIGURATION



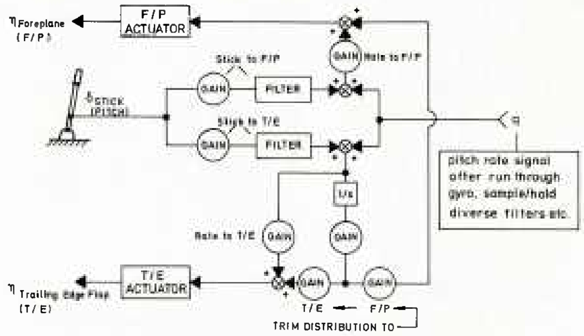


FIG. 18 SIMPLIFIED LONGITUDINAL CONTROL SYSTEM

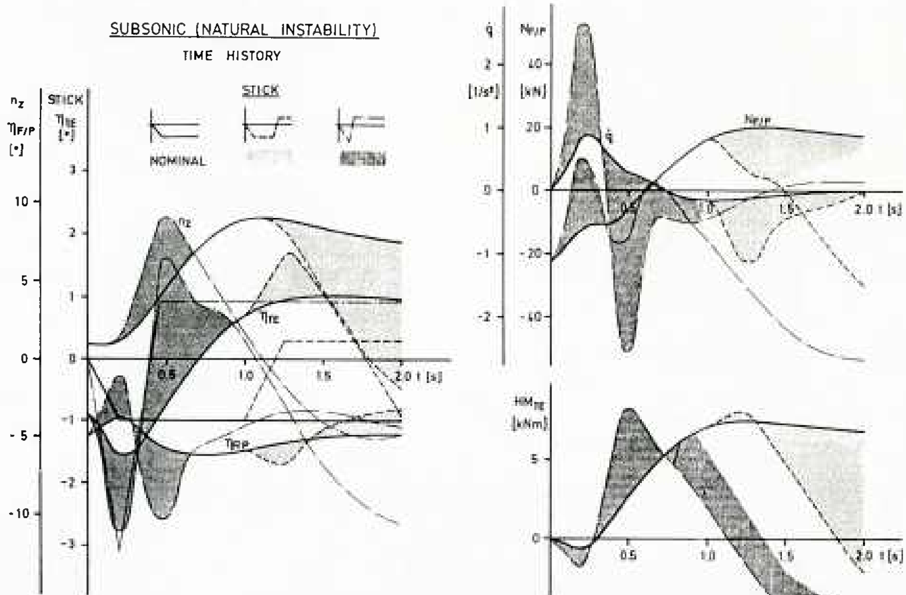


FIG. 19 INFLUENCE OF CONTROL INPUT FUNCTION ON MOVEMENT AND LOADS OF CONTROL SURFACES

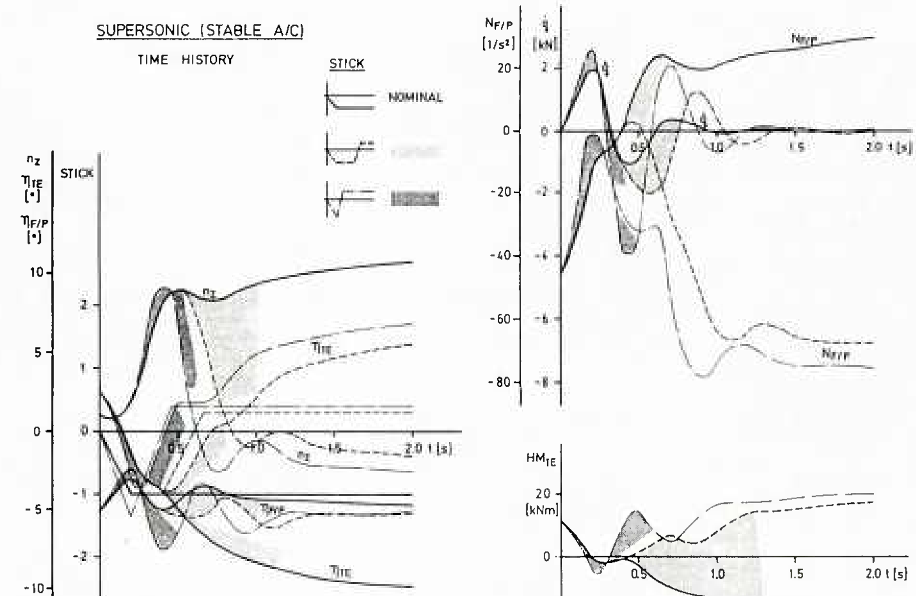


FIG. 20 INFLUENCE OF CONTROL INPUT FUNCTION ON MOVEMENT AND LOADS OF CONTROL SURFACES

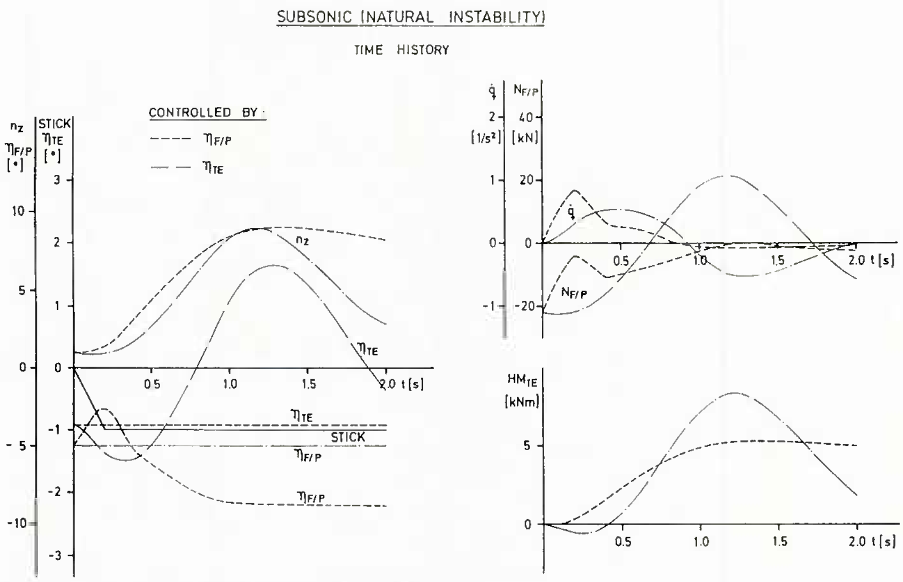


FIG. 21 MOVEMENT AND LOADS OF CONTROL SURFACES CONTROLLED BY FOREPLANE OR TRAILING EDGE FLAP

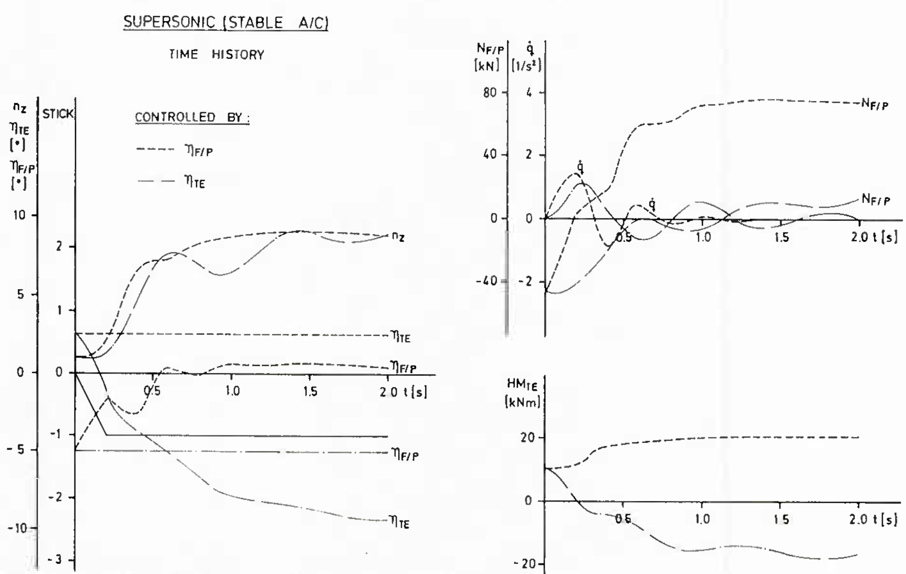


FIG. 22 MOVEMENT AND LOADS OF CONTROL SURFACES CONTROLLED BY FOREPLANE OR TRAILING EDGE FLAP

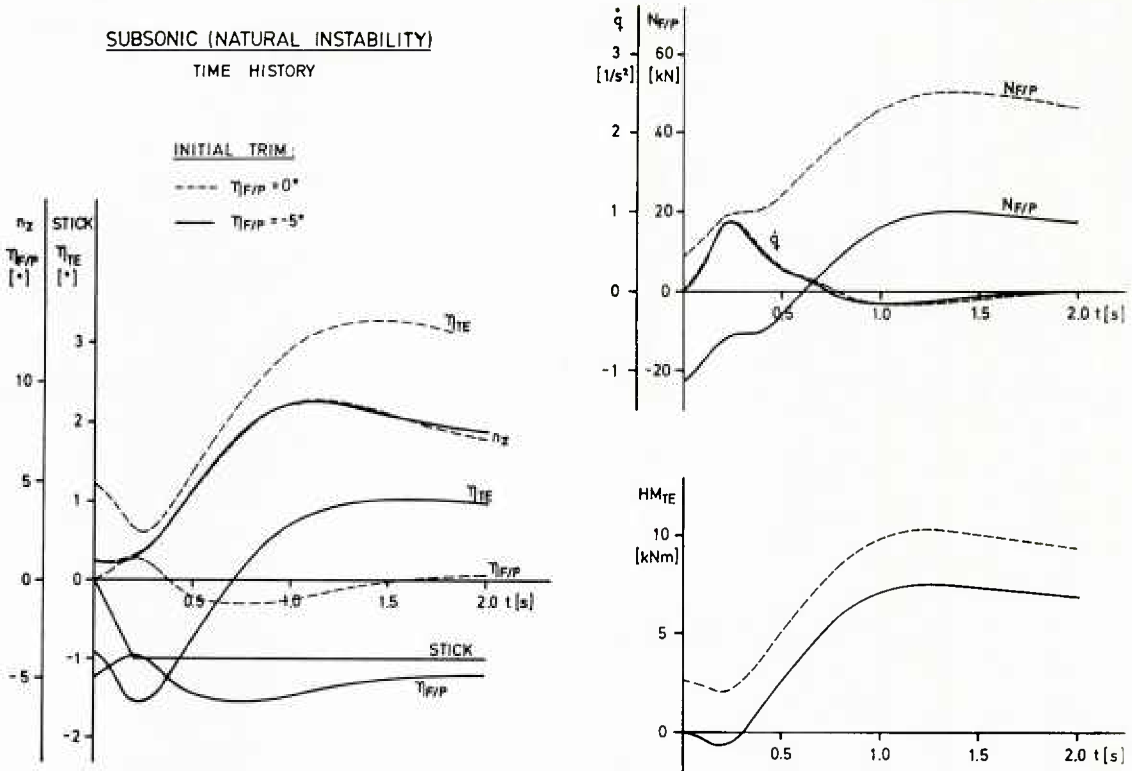


FIG. 23 INFLUENCE OF INITIAL TRIM ON MOVEMENT AND LOADS OF CONTROL SURFACES

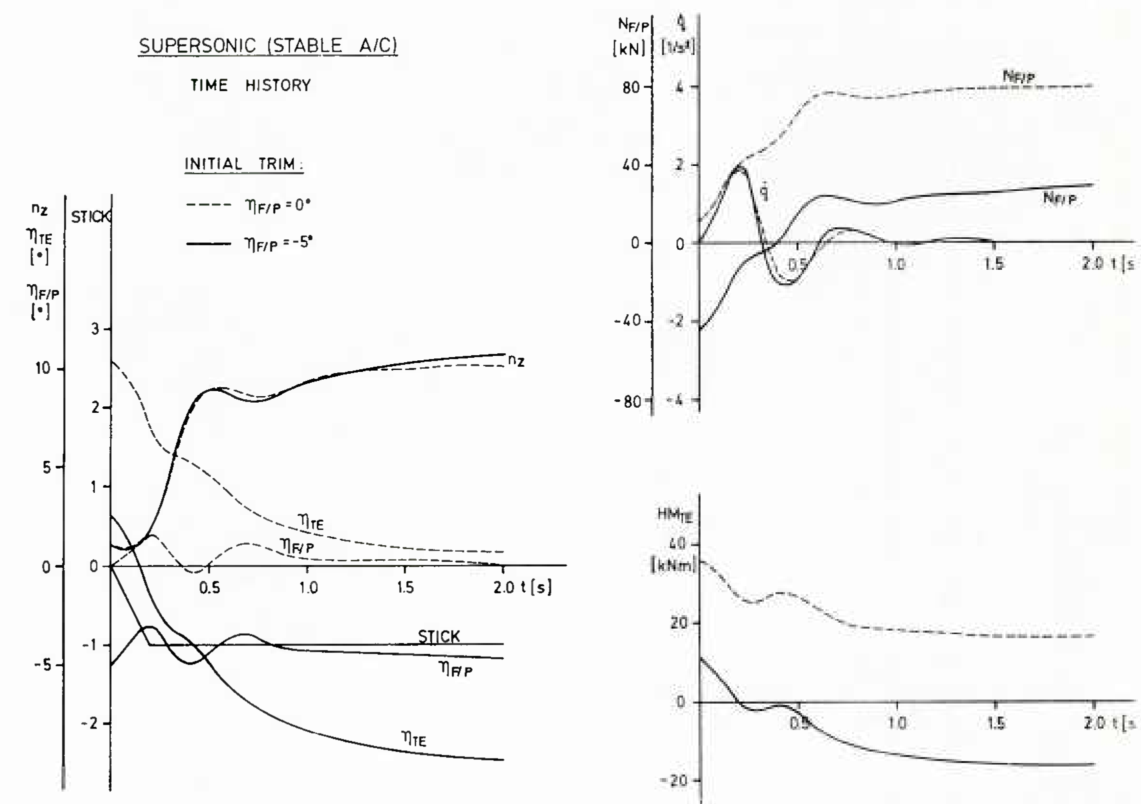


FIG. 24 INFLUENCE OF INITIAL TRIM ON MOVEMENT AND LOADS OF CONTROL SURFACES

5. CONCLUSION

The relevant regulations do not make any distinction between aircraft with active control and conventional aircraft. That means there will be a difference between the control deflections defined in regulations, for example the primary cockpit control displacement, and the control surface deflection. If there is no similarity between the time history of the cockpit control and of the control surface deflection, the task of determining the extreme loads on the main structural components is very complex. To solve this problem, the specialists for handling qualities, performances, and system design should be consulted regarding the consequences on loads and the essential parameters which are influenced by modern control systems.

In such an interactive process, the architecture and the gain of the control system will be optimized both for handling qualities and for structural loads within the whole flight envelope. To cope with all modifications during the development of an aircraft, as there are aerodynamic data, stiffness, mass distribution and those of the control system, the margins of the control system gain have to be analysed and applied carefully on determination of the design loads.

In the future another approach to the evaluation of operational manoeuvres should be pursued. Such an evaluation will analyse the time history of relevant parameters and can determine the control surface deflections. [3] The extreme operational parameters can be analysed and the corresponding control surface deflections derived from the results of the analyses. In Fig. 25 an example for the time history of the extreme control surface deflections is shown.
The benefits of this evaluation are:

- the relationship to the operational parameters is established

- the correlation between activated control surface deflections is a realistic one.

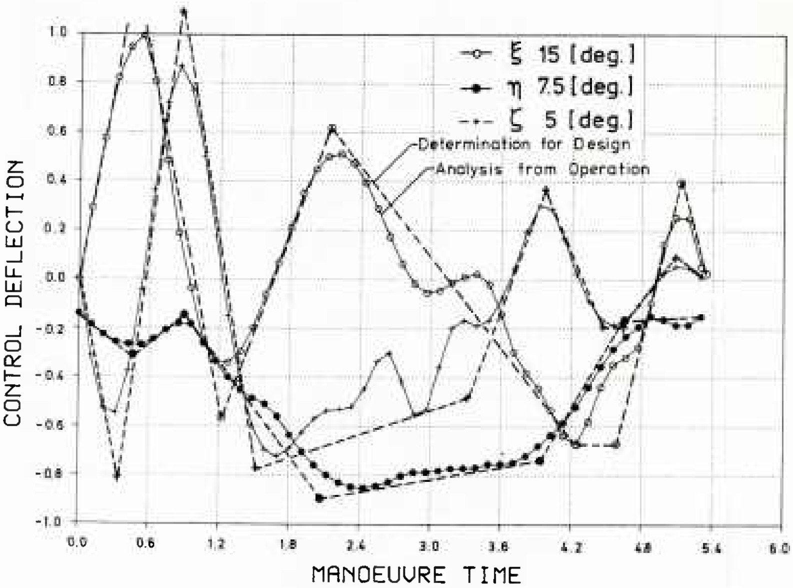


FIG. 25 EXTREME OPERATIONAL CONTROL SURFACE DEFLECTIONS (HIGH-6-TURN)

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[1] MIL-A-8861 (ASG)
Airplane Strenght and Rigidity, Flight Loads

[2] MIL-A-008861 A (USAF)
Airplane Strenght and Rigidity, Flight Loads

[3] AGARD CONFERENCE PROCEEEDING No. 375
Operational Loads Data, Page 13
Evaluation of Operational Loads to verify Structural Design
by H. Struck

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